CMHC
Canada Mortgage
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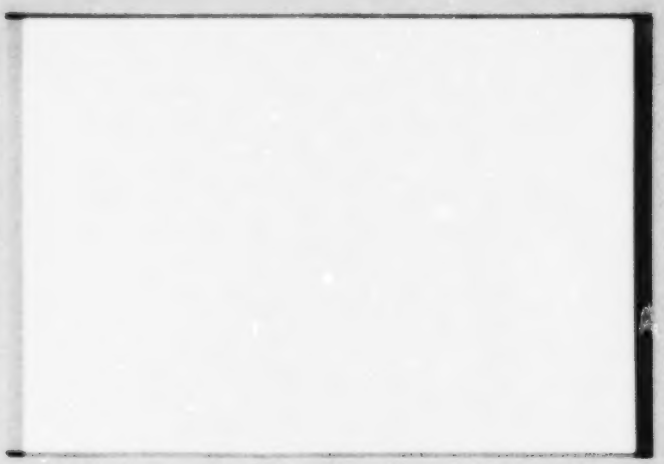

SEMINAR
HEATING SYSTEMS
FOR ARCTIC AND SUB-ARCTIC CANADA

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Submitted to:

Canada Mortgage and Housing Corporation

By:

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Appendix A

1.0 INTRODUCTION

This report is an extension of a prior discussion document, examining the merits and disadvantages of forced air and hydronic heating systems for use in northern housing.

The prime purpose of the document was to elicit comment from knowledgeable people in order that some consensus could be obtained on the most appropriate heating systems for use in northern housing. The ultimate goal was to identify guidelines for the approval of heating systems most appropriate for the northern situation.

This is not a simple task.

The fact that both forced air and hydronic systems, in a number of different variations, are in use and being installed in current arctic construction indicates that no clear consensus exists. Experience has shown that there are systems of both types which perform well in a northern environment, and systems of both types which do not perform adequately.

Heating systems are only one component of the building design and, therefore, how they integrate with the rest of the building components greatly affects their suitability and potential. There are so many factors involved, that a definitive answer to the question of suitability is not going to be available. It is hoped, however, that, by drawing from the experience and expertise of proponents of the various systems, the factors which tend to favour one system or another can be pointed out, so that housing authorities will have a better idea of what types of systems will most likely be successful in a particular situation.

Buchan, Lawton, Parent Ltd. was engaged to write the previously noted discussion document with the understanding that it would be sent out for review to a number of housing industry experts for comment.

It was hoped that comment, to the point of argument, would be elicited from reviewers of this document. The experience and expertise of these people would allow a much more valuable evaluation to take place.

A seminar was arranged by the Canada Mortgage and Housing Corporation for June 10, 1985 to discuss the document and issues involved. Appendix A contains a list of the attendees. Based on the discussion of this meeting, the original discussion document was revised. This is the product of that revision.

2.0 EVALUATION CRITERIA

In order to make a full evaluation of the merits of hydronic and forced air heating systems, a broad range of interrelated factors must be considered. Some factors can be reasonably be quantified, while the ranking of others is highly subjective. For this document, the factors considered included:

- how the heating system affects building design;
- how the selection of the heating system affects the construction of the unit in the northern environment;
- the maintenance requirements and their impact on the suitability of the system;
- how the systems perform in achieving the function of providing a comfortable environment for people to live;
- the safety of the systems to the occupants and to the dwelling;
- what were the long term health issues included;
- how acceptable the systems are to the envisioned occupants of the houses;
- how the heating system can be integrated with other mechanical systems;
- what the effect of emerging building technology will be on the selection of the heating system.

Basic categories and sub-categories were identified. A complete list of the categories and sub-categories is included in Section 5.0, and some notes and explanations on the categories are included in Section 6.0.

3.0 THE SYSTEMS EXAMINED

There are any number of variations and hybrids of the two basic types of heating systems -- the forced air heating system and the hydronic heating system. The evaluation in this discussion document has been limited to four systems which were felt to be the most common. It is hoped that the evaluation methodology can be applied to other variations with relative simplicity.

In defining the system, current technology was considered a primary limitation. For example, while there has been some research on items such as high efficiency condensing oil-fired systems, the technological problems associated with the very acidic condensate must be resolved prior to arctic application.

The four systems selected are defined as follows:

System 1 - Forced Air Heating System

This system, as shown schematically in Figure 3.1, consists of a conventional oil-fired, forced air furnace, duct distribution with balancing dampers in each major duct branch and dampered registers in each room. Ducting is in the walls above the ceiling or boxed in. A false floor is not used. Warm air is passed to floor level down interior walls. Building ventilation is provided by conventional exhaust fans (in the kitchen and/or bathroom). Domestic hot water is supplied by a separate DHW heater.

System 2A - Conventional Hydronic Heating System

This system, as shown schematically in Figure 3.2, consists of an oil-fired boiler and a single circulating pump distributing the glycol solution to fin-coil units in a series loop. The piping is surface mounted or boxed in. Fin-coil units are housed in cabinets with manual dampers to control convective air movement. There is a conventional exhaust fan in the bathroom, and perhaps the kitchen. Domestic hot water is supplied by a separate DHW heater.

System 2B - Zone Controlled Hydronic System with Integrated Domestic Hot Water

This system, as shown schematically in Figure 3.3, is being installed primarily in private residences. Zone control is provided by motorized valves. Zones are usually the first and second floor. DHW is supplied by a coil in the boiler.

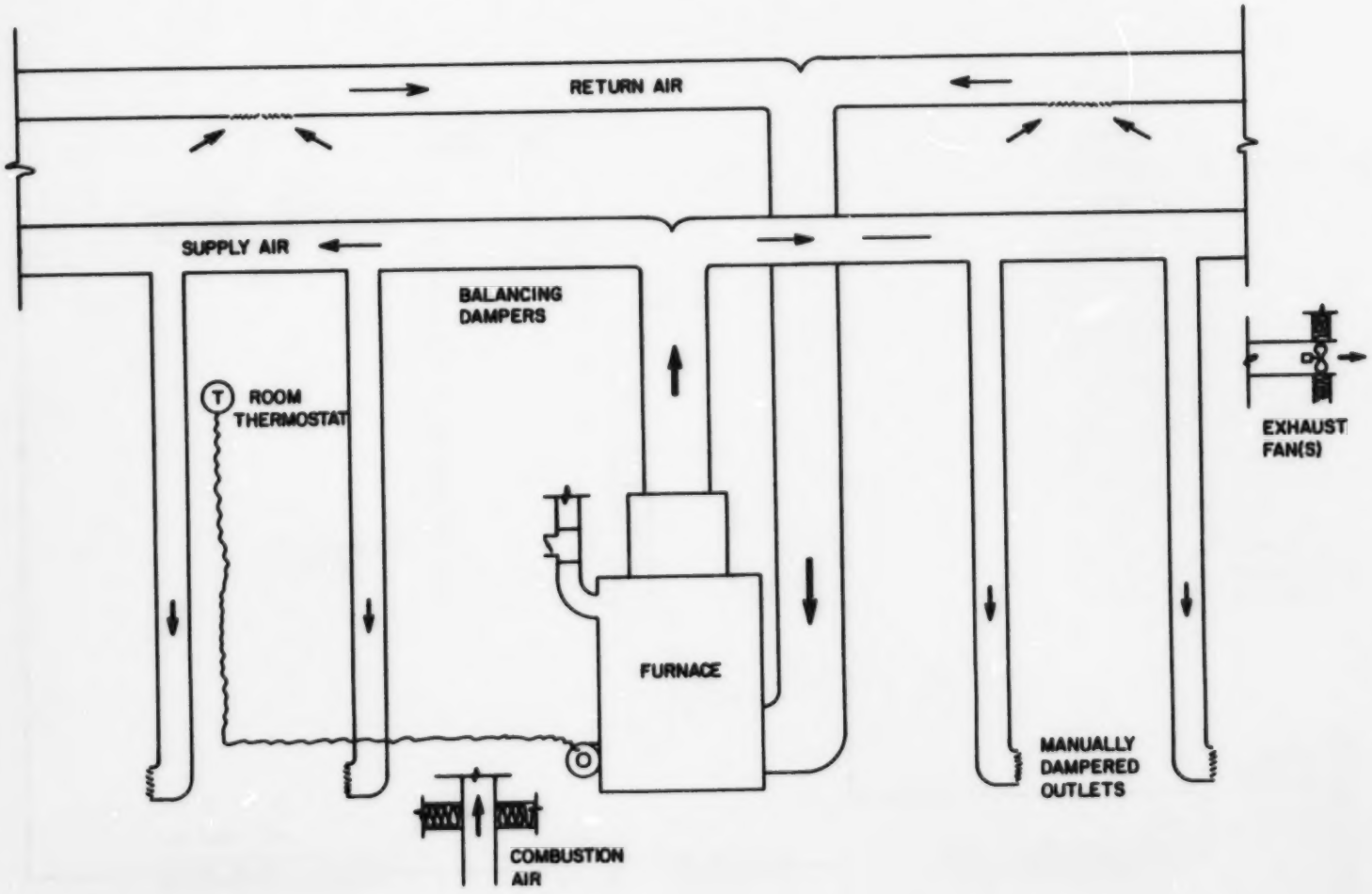

Figure 3.1 CONVENTIONAL FORCED AIR HEATING SYSTEM

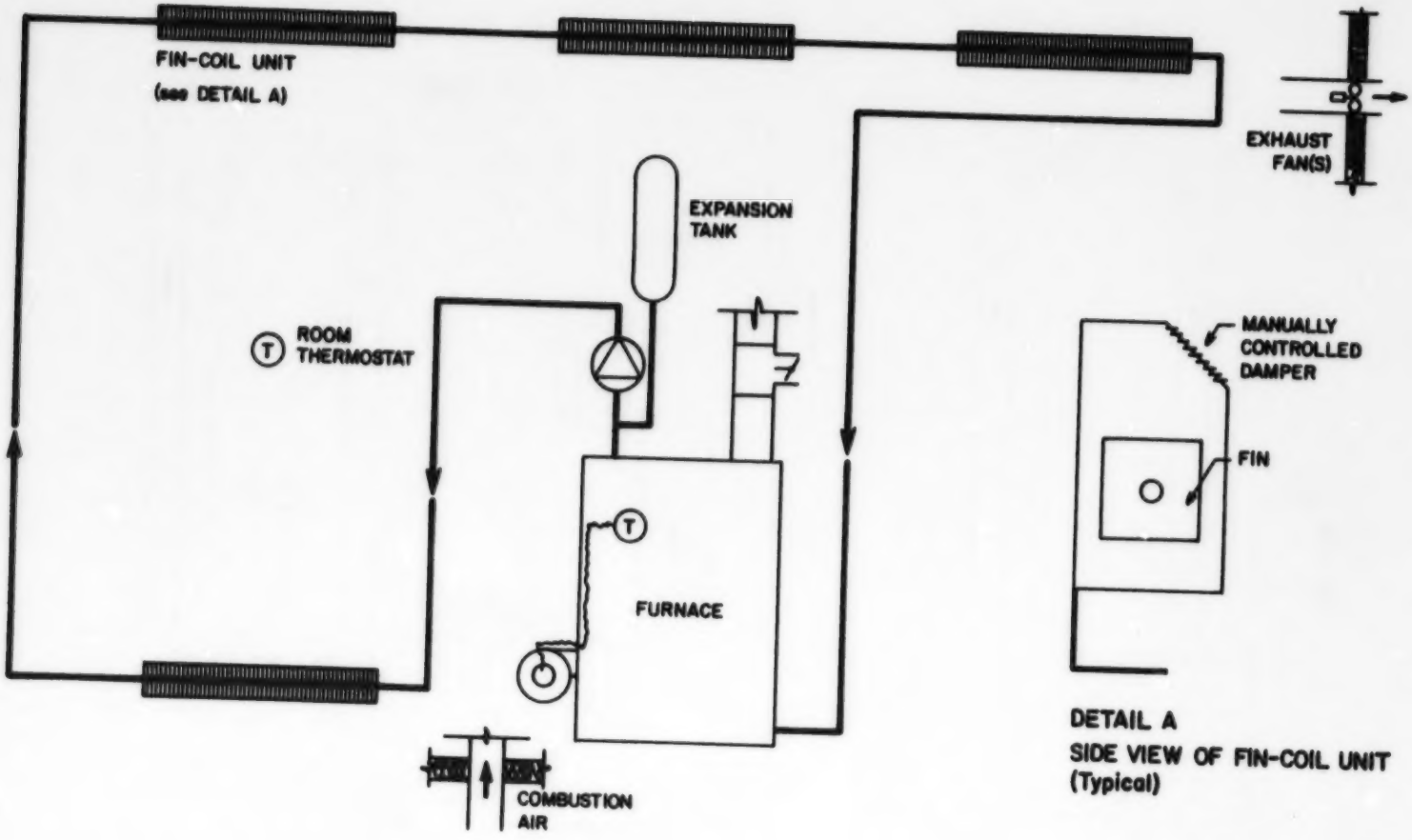

Figure 3.2 CONVENTIONAL HYDRONIC HEATING SYSTEM

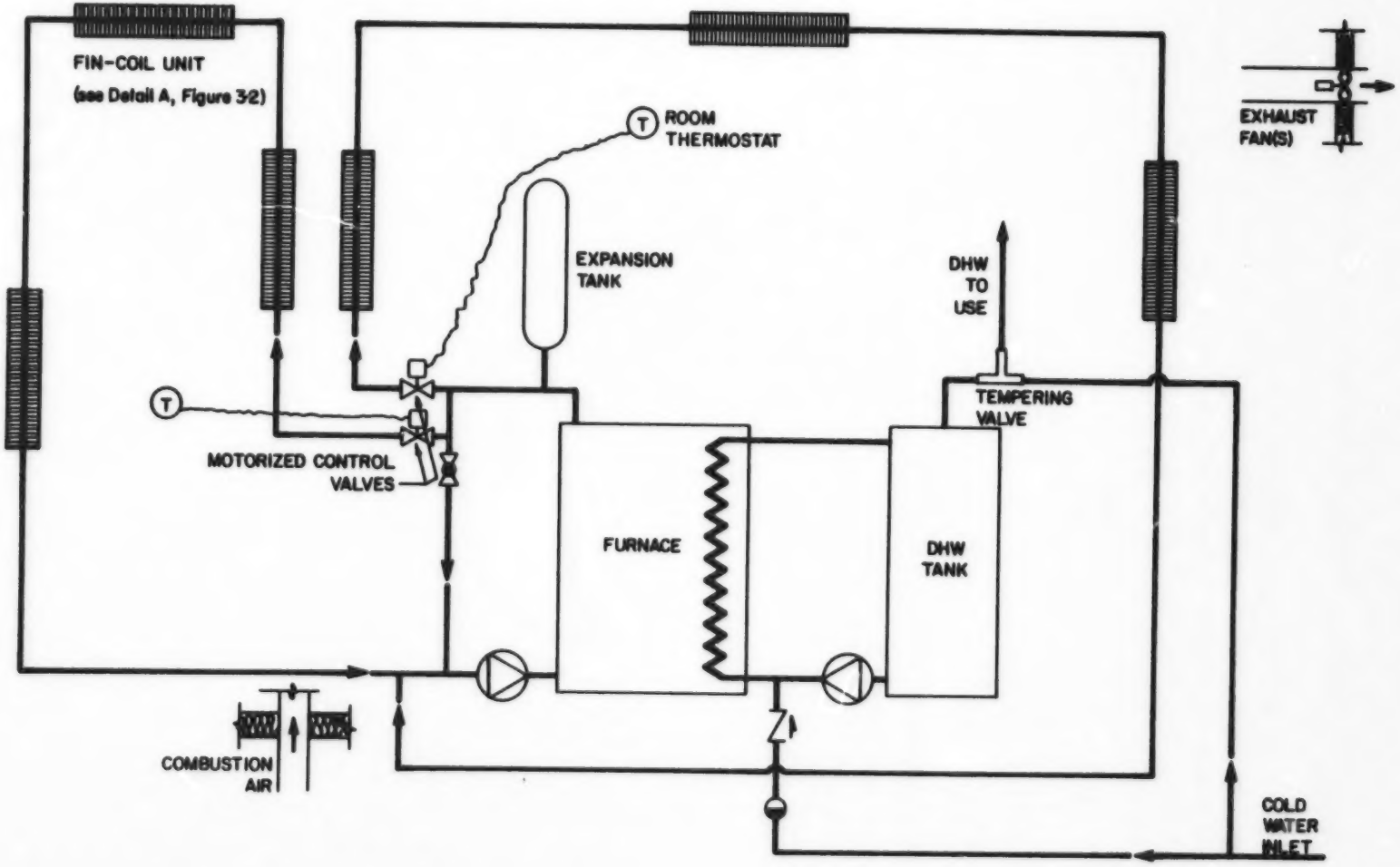

Figure 3.3 ZONE CONTROLLED HYDRONIC SYSTEM WITH INTEGRATED DHW

System 3 - Hydronic Heating System with Air Circulation System

System 3, as shown in Figure 3.4, consists of a conventional hydronic boiler system with fin-coil units, and an air circulation system incorporating a circulating fan and a fresh air make-up duct. Conventional exhaust fans are also included. This particular system was selected for evaluation because it is currently being installed by the NWTHC.

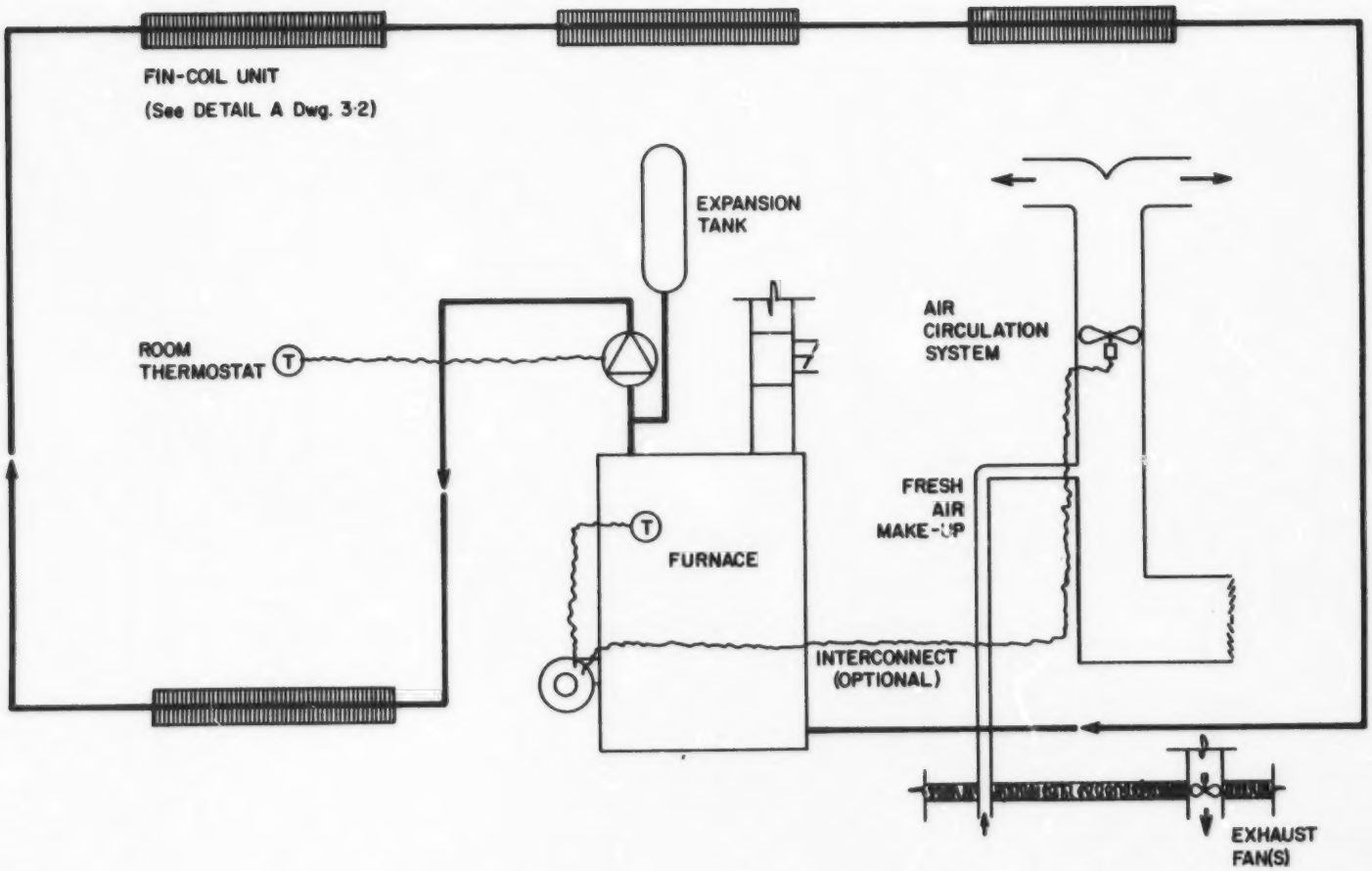

Figure 3.4 HYDRONIC HEATING SYSTEM WITH AIR CIRCULATION SYSTEM

4.0 EXPLANATION OF THE RATING SYSTEM

The technical evaluation process has been broken down into two components. The first involves ranking the various systems quantitatively in each of the evaluation categories. The second part consists of putting a weighting on the importance of each of the evaluation criteria to the overall system evaluation. By multiplying the numeric value of the rating by the numeric value of the weighting factor, and totalling the result of all categories, a numeric evaluation factor can be obtained. Obviously there can be much discussion and argument of either the weighting or ranking factor. Those shown are the consensus of the June 10th seminar.

System costs are treated separately but in a similar manner. The ranking of costs was based on estimated installed costs above that of a forced air system (excluding chimney and oil tank. Maintenance and repair costs were based on a present value cost of annual maintenance based on the following assumptions:

System life	n = 15 years
Escalation Rate	e = 8%
Interest Rate	i = 11%

The equation for determining Present Value (PV) of an annual cost is

$$PV = A \times \frac{\left(\frac{1+e}{1+i}\right)^{n}}{\left(\frac{1+i}{1+e}\right) - 1}$$

when A is current annual cost.

Using the above assumptions, therefore, the annual cost is multiplied by 23.9 to get the Present Value.

It was assumed that the fuel costs for all the systems would be the same but, because of the very high electricity costs in some locations in the arctic, power cost was considered separately assuming $.50/kWh.

4.1 The Ranking System

Under each of the technical evaluation categories, the systems were given a numeric ranking based on the following scale:

4 - excellent
3 - good
2 - adequate
1 - marginal
0 - poor

For costs, the assumed ranking scale was:

4 - within $500 above a forced air system
3 - within $1500 above F/A system
2 - within $2500 above F/A system
1 - within $3500 above F/A system
0 - more than $3500 over F/A system

Section 5.0 shows the ranking of the four defined systems based on the seminar consensus and Section 6.0 contains notes justifying the decisions.

4.2 Weighting Factor

Obviously, assigning importance to the various factors is important and difficult. The method used in Section 5.0 is to assign a factor of one to each of the eight technical evaluation catagories, and to divide this total amongst the sub-categories. Judging how realistic this weighting is and proposing alternatives are an important task for the designer.

System costs have been weighted in a similar manner with a total weighting of 3.0 in total.

The weightings shown in Section 5.0 were based on the June 10th seminar consensus.

5.0 RANKING MATRIX

Safety and Health - not rated
Occupant Acceptability - not rated

5.1 TECHNICAL EVALUATION CATEGORIES

SYSTEM	1	2A	2B	3	WEIGHTING FACTOR
DESIGN FACTORS					
Effect on Function of Building Design	2	4	4	2	.1
Effect on Aesthetics of Building Design	2	2	2	2	.1
Space Requirements	2	2	2	2	.1
Incorporation into Current Construction Methods					
- Panel Construction	2	4	4	3	.1
- Stick Built	3	4	4	3	.1
- Exposed Floors	3	3	3	3	.1
Ease of Incorporating - Combustion Air Supply	3	3	3	3	.1
- Controlled Ventilation	3	2	2	3	.1
- Heat Recovery Ventilators	3	2	2	3	.1
- Air Cleaning Systems	3	0	0	3	.1
	2.6	2.6	2.6	2.7	1.0
CONSTRUCTION FACTORS					
Skilled Labour Requirements	2	2	2	2	.2
Weather Dependence	3	2	2	2	.15
Scheduling Flexibility	1	4	4	3	.2
Ease and Security of Shipping	3	3	3	3	.15
Availability of Components On-Site	2	2	2	2	.15
Start-up and Commissioning Requirements	3	2	2	2	.15
	2.45	2.55	2.55	2.35	1.0
MAINTENANCE FACTORS					
Maintenance Requirements - Skills Required	2	1	1	1	.3
- Effort Required	2	2	3	2	.3
- Ease of Diagnostics	3	3	3	2	.3
Availability of Replacement Parts	4	2	2	2	.3
Durability	2	3	3	3	.2
Effect of Poor Maintenance	3	2	2	2	.3
Extent and Effect of Failure	3	2	2	2	.3
	5.5	4.5	4.8	4.2	2.0
PERFORMANCE FACTORS					
Controlability	3	3	3	3	.4
Temperature Distribution	3	1	2	3	.4
Floor Temperature	3	2	2	2	.3
Humidity Control	2	1	1	1	.3
Response to Changing Conditions	3	1	2	2	.3
Noise Level	2	4	4	2	.3
	5.4	4.0	4.7	4.5	2.0

ADAPTABILITY TO VARIOUS BUILDING TECHNOLOGIES					
Tighter Buildings	3	3	3	3	.25
Higher Insulation Levels (See standards)	3	3	3	3	.25
Two-Storey Houses	3	2	3	3	.25
Cathedral Ceilings/Heated Attics	3	2	3	3	.25
	3.00	2.5	3.00	3.00	1.0
TOTAL - Technical Categories	18.95	16.15	17.65	16.75	7.0
5.2 COSTS					
Installed Capital Costs	4	3	3	2	.75
Maintenance and Repair Costs	4	3	4	3	.75
Fuel Costs	0	4	4	0	.75
Power Costs	5	10	10.5	3.5	.75
TOTAL - Costs	6	9	9.75	5.25	3.0
TOTAL RATING	24.95	25.15	27.4	22.0	10.0

6.0 NOTES ON THE RANKING OF THE SYSTEMS

6.1 Safety

Safety was not considered a ranking category because a safe system is mandatory, and certification mechanisms exist. Some discussion points worth noting include the following:

Any combustion appliance has the potential of creating a fire. The risk is about equal with forced air or hydronic systems. The risk of burns or scalds are slightly greater with hydronic systems, especially if control systems and liquid temperatures and pressures are not maintained properly. If the DHW system is integrated with the heating system, there is one less burner. Logically, this would reduce fire risk.

6.2 Occupant Acceptability

Occupant acceptability was not ranked because a minimum level of satisfaction is mandatory, and it is, for the most part, related to the performance of the heating system.

6.3 Design Factors

6.3.1 Effect on Function of Building Design

In order to provide for simple and efficient duct runs, some compromises with functional layouts of walls, etc., may be required for forced air (F/A) systems. Because of the flexibility of a piping distribution system, these compromises are less necessary with hydronic systems. Therefore, hydronic systems would seem to be favoured in this category.

6.3.2 Effect on Aesthetics of Building Design

The type of heating system could have a bearing on how an architect or designer lays out and finishes a house. This is more a function of the distribution system than the furnace or boiler itself. It is more difficult to lay out, and hide or disguise, ducting than piping. Therefore, the use of a F/A heating system may limit the designer's flexibility with regard to wall placement, ceiling type, etc.

On the other hand, the registers of a forced air heating system are less intrusive and the interior space may be more pleasing to the eye because of it. On balance, there is no clear advantage.

6.3.3 Space Requirements

When considering both the unit and the distribution system, the F/A system may require more space. Much of it can, with some effort, be included in what would otherwise be waste space, i.e. inside walls, above ceilings or under floors. The radiators or fin-coil units of a hydronic system take up valuable floor space. The heating units themselves are both relatively compact and require approximately the same amount of dedicated space.

6.3.4 Incorporation Into Current Construction Methods

Until relatively recently, most arctic housing used prefabricated, stressed skin panel construction. In this type of construction, incorporating forced air systems was more difficult than hydronic systems, which could have all their distribution systems and radiators surface mounted. More recently, stick built units have become quite common. It is much easier to incorporate duct systems into this type of construction, although it involves the addition of another item to be considered in the construction scheduling. In either type of construction, it is desirable to run ducting in interior walls or above ceilings. This may compromise the location of registers.

An almost universal feature of arctic housing is insulated floors above unheated space. This limits the option for putting the heating distribution system in the floor. Using a sub-floor to provide duct space is expensive and creates construction scheduling problems at times, but it is one way of solving cold floor surface temperature problems.

The air movement associated with F/A systems also reduces cold floor problems.

6.3.5 Ease of Incorporating Air Handling Systems

In tight houses, there is a definite need for a combustion air supply and controlled ventilation.

The difficulty of providing a suitable combusion air supply is common to all systems.

There are differences, however, when considering how to handle incoming ventilation air. The F/A system has an inplace distribution system but consideration must be given to how to dilute or temper the cold inlet air. This is easier with a hydronic coil. Heat recovery ventilators partially temper the incoming air so further tempering is less of a problem, although it may still be necessary.

A centralized air handling system has an advantage when considering air filtering or cleaning systems.

6.4 Construction Requirements

6.4.1 Skilled Labour Requirements

Both of the systems require a qualified burner technician to properly install and set up the heating system. Ducting arguably requires less skill than the high quality plumbing required for glycol systems but a plumber is required on-site during construction in any case.

6.4.2 Weather Dependence

Depending on the building design, it may be possible to start up a warm air system sooner than a hydronic system. This would allow the heating of the building to speed construction, but the difference is relatively minor.

6.4.3 Scheduling Flexibility

This category is highly dependent on building design. Surface mounted hydronic systems have an edge because it is possible to almost ignore the furnace and heating system till the rest of the building is virtually complete. Ducting, which is generally run through walls or floor spaces, usually must be scheduled into the busy construction period.

6.4.4 Ease and Security of Shipping

Because of the relatively bulky nature of ducting, especially the pre-formed sections, shipping is more difficult. There have been incidents where boilers have arrived with damaged boiler cores. This was attributed to poor crating practices.

6.4.5 Availability of Components On-site

Often there isn't very much of anything on-site in a lot of northern communities, but since F/A systems are more common, some parts are likely to be found. There is the likelihood of finding plumbing supplies on-site and it is possible, if necessary, make up sheet metal work for ducting.

6.4.6 Start-up and Commissioning Requirements

Because of the relatively large amount of air circulation with forced air systems, the balanced design of the system is less critical than with the hydronic system. This is fortunate since it is seldom done.

6.5 Maintenance Factors

6.5.1 Maintenance - Requirements

Skills Required

Both systems require a commodity which can be relatively hard to find in northern communities -- skilled maintenance personnel. Because there are more forced air systems currently in operation, there is more likely to be people familar with this type of system than with hydronic systems.

Effort Required

Because of the fan belts and filter on the forced air system, those systems require more regular maintenance than a hydronic system, although the authors of this document feel that, in northern applications, the units must be serviced at least twice a year.

One unique concern with arctic housing is the handling of stone dust from carving activities. This puts a special emphasis on servicing of the filters of a forced air system. Filters can get weighed down by stone dust in a remarkably short period of time.

Hydronic systems add a pump, control valves and glycol to the maintenance requirements. Experience with the controllers has not been good.

Ease of Diagnostics

The trouble-shooting of inoperative or poorly performing units requires more skill than regular maintenance, but neither type of system seems to have a clear advantage.

6.5.2 Availability of Replacement Parts

Because of the wide use of F/A systems in the north and the rest of Canada, parts are more generally available. This may change as boilers become more commonly applied.

6.5.3 Durability

In southern applications, boilers have a longer life than furnaces. Whether this will hold true in the arctic is arguable.

6.5.4 Effect of Poor Maintenance

Poor maintenance will probably show up in the performance of a forced air system sooner than with a hydronic system. However, the consequences of poor maintenance with a hydronic system can be more severe.

6.5.5 Extent and Effect of Failure

Failure of the piping system in a hydronic system could cause a significant amount of physical damage to a building.

6.6 Performance

6.6.1 Controllability

Because of the air circulation of the forced air system, forced air systems are more controllable and react more quickly than hydronic systems. This also makes them difficult to "zone" if different rooms are to be kept at different temperatures.

6.6.2 Temperature Distribution

Air circulation of the forced air systems limits temperature stratification and room variances, especially if a two-speed fan is used.

6.6.3 Floor Temperatures

F/A systems reduce stratification due to cold floors. If heating the floor is desirable, F/A systems would also have an advantage.

6.6.4 Humidity Control

A forced air system is clearly superior when it comes to adding moisture to dry air because it can be fitted with a central humidifier. Unfortunately, this can create problems, especially if the humidifier is not set properly. Because of the extremely cold climate, relatively low winter humidity levels must be maintained to avoid condensation.

6.6.5 Response to Changing Conditions

Because hydronic systems are slower to react and more prone to temperature distribution problems, changing conditions such as the shifting of the wind direction will create more comfort problems than with forced air systems.

6.6.6 Quietness

Fan noise and duct vibration in a forced air system can be considerable and constant. A properly filled glycol system should be virtually noise-free.

6.7 Adaptability to Various Building Technologies

6.7.1 Tighter Buildings

The tighter buildings become, the greater the requirement will be for some kind of controlled ventilation system and fresh air supply and circulation. This gives forced air systems an advantage. Conversely, tighter buildings would be more energy efficient and the sizing problems will become more pronounced making DHW integration more attractive.

6.7.2 Higher Insulation Levels

Higher insulation levels should only effect the size of furnace required. When considering the difficulty in finding either low output furnaces or boilers, higher cyclic loses could be expected.

6.7.3 Two-storey Construction

Many more buildings in northern climates are being built with a two-storey format. Two-storey buildings impose a higher potential for temperature stratification which single zone hydronic systems may have trouble overcoming. Having the second floor gives a good location for duct runs. Therefore, two-story construction would seem to favour forced air heating systems slightly.

6.7.4 Cathedral Ceilings/Heated Attics

Recently, there has been a trend away from attic-type ceilings and toward either cathedral ceilings or uninsulated ceilings with a "heated attic". In either of these types of construction, finding space for duct runs is relatively simple. There is also higher potential for temperature stratification. Therefore, this type of construction would favour forced air systems.

6.8 Costs

6.8.1 Installed Cost

Obviously, the installed cost of a system can vary greatly with the design of the building. The authors of this document feel that a realistic estimate of the difference in costs between a hydronic system and a forced air system is approximately $1500. This would quickly be reduced or eliminated if a false floor was deemed necessary. Adding a separate air circulating system would add about $1000. Integrating DWH could save about $300.

6.8.2 Maintenance and Repair Costs

The authors estimate that there is very little difference in the regular maintenance costs of hydronic and forced air systems. If a separate circulating system is used, some additional monies for maintaining this system must be allowed, but it is relatively minor amounting to approximately $25/yr. Hydronic systems probably incur sightly higher repair costs, attributable to pump, valve control and pressure relief valve repairs, which are more costly to repair than fan motors. It is estimated that a hydronic system probably costs about $25 per year more to repair.

One other significant maintenance item for hydronic systems is the replacement of glycol. It is felt that glycol will be replaced, on average, once every five years at a current cost of approximately $150. The present value of this replacement over a fifteen year life would be about $250.

6.8.3 Fuel Costs

Barring a dramatic development from current technology, fuel costs should be similar.

6.8.4 Electrical Power Costs

A rough estimate of power consumption for an air circulating fan, operating constantly on high speed, is about 1000 to 1200 kWh/yr. It may, in reality, be lower. If the fan is operated at low speed for 70 percent of the time and high speed for 30 percent of the time, the power consumption drops to about 700 kWh/yr.

A water circulating pump probably uses about 250 to 425 kWh/yr. Depending on fan load and scheduling, the difference in electrical requirements is significant when the electricity costs encountered in some arctic communities are taken into consideration. The cost per unit heating value for fuel is about one-tenth as for electricity.

7.0 COMMENTS AND RECOMMENDATIONS

1. While either type of system can be made to work, this analysis indicates that forced air heating systems have a slight performance advantage for arctic and sub-arctic housing. The one major advantage of hydronic systems is their flexibility in design and construction.

2. The electrical cost for operating circulating fans in current forced air systems is very significant in many arctic communities. While it can be argued that all arctic houses need air circulation for reducing temperature differences and distributing ventilation air, this factor seems to favour hydronic systems in these communities. In any case, there seems to be a significant potential for reducing air handling costs in the arctic which require some investigation. Specific areas of interest include:

   - high efficiency fans for both new and retrofit applications,
   - the use of low resistance ductwork components,
   - the optimization of air flow rates,
   - the development of systems which use natural driving forces to assist in air movement (passive ventilation).

   These issues are somewhat specialized to remote community applications because of the high power cost/fuel cost ratio associated with diesel generated electricity.

3. The integration of DHW heating with the heating system is conceptually very attractive with hydronic systems, but hard information on the relative efficiencies of separate and integrated systems is needed.

4. One important consideration in the system selection process is ensuring that personnel familiar with the operation and maintenance of the system will be available.

The discussion which resulted in this document suggested some important design principals for either type of system.

Forced Air
- use two speed fans;
- do not use overhead outlets;

- false floors to allow duct distribution are expensive and create construction difficulties. It is possible to run ducts overhead with distribution to floor levels down interior walls, but false floors are well liked because they are generally warmer;
- proper placement of thermostats is critical;
- balancing of system is important.

Hydronic

- a second floor needs a separate zone control;
- proper placement of thermostats is critical;
- correct sizing of heat distribution system is critical since "balancing" capabilities are more limited than with a forced air system.

Highlights From June 10, 1985 Seminar

One issue raised during the seminar was the future development of mechanical systems for arctic applications and priorities for research. This discussion was centered around a presentation by Peter Russell of CMHC. He presented a list of priorities including:

- safety
- health - separate ventilation air from combustion air and exhaust
  - continuous controlled ventilation
- reliability - simple servicing and operation
  - faulty operation should be apparent
  - plumbing should always be accessible (concerned about some hydronic systems)
  - stand-by non-electrical space heating
- comfort - including tempered inlet air, humidity control, warm floors, air quality and noise level
- effect on structure - normal operation at negative pressures to minimize condensation in envelope
- environmental impact - potentially acidic condensate from high-efficiency oil burner should be neutralized before release
- economy - low use of electricity
  - high efficiency water heater
  - ventilation air heat recovery
  - higher initial cost justified by operational performance
- predictable performance - regardless of site and house conditions
- standardization - for economy of design and manufacturer servicing and spares
- flexibility - suitable for wide variety of circumstances

APPENDIX A

Some comments from the discussion are important.

1. Costs of sophisticated systems and backup systems concerned some people.

2. Conventional space heaters have a poor record with respect to overall safety. There was interest in a newer type which has a draft fan. This could serve as a primary system in low energy houses.

3. In very energy efficient buildings, heating requirements are so low that it may be possible to use the technology of instantaneous water heaters to provide space heating and DHW.

4. Some concern was expressed with the number of openings in the envelope (for separate air supplies and exhausts). It was suggested that some of these could be concentric ducts.

5. There was a general concensus that controlled ventilation was a future requirement, preferably with heat recovery.

6. The electrical cost of moving air was a real issue in the arctic. High efficiency fans and/or use of natural driving forces were areas requiring more development.

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May 8, 1985

ATTN:

RE: Seminar June 10th, 1985
9:00 a.m. Second Floor
Conference Room

Heating Systems for
Arctic Canada

PERSONS ATTENDING:

Mark Lawton (Chairman)	Consultant
Jack Peirson	Contractor (AGRENA)
Matt Matherman	Engineer (AGRENA)
R. Bushell	N.W.T.H.C.
Glen Tucker	Frobisher Bay Ho. Assn.
(REPRESENTATIVE)	CMHC Yellowknife
Bertrand Roy & Colleagues	S.H.Q.
R.W.C. Chill	DIAND
Ken Latta	NRC
Rob Duncan	CMHC
Peter Russell	CMHC
Michael Pine	CMHC
Mark Riley	EMR

NOTE: Others may be invited to attend as participants or as observers.

Canada